Experiment 15

SYNTHESIS OF ACID-BASE INDICATORS

Objective

The purpose of this experiment is to learn the structures, syntheses, and color changes of the acid-base indicator phenolphthalein and its derivatives.

Lab techniques

- Operating the sand bath, precipitation, and decantation

Introduction

I. Preparation of phenolphthalein indicator and its color change

Phenolphthalein is a commonly used acid-base indicator. It is colorless when the pH of the solution is lower than 8, and appears purple-red when the pH rises above 9. The synthesis of phenolphthalein is a series of electrophilic aromatic substitution reactions. The general mechanism is shown in Fig. 15-1. An electrophile (a species that accepts an electron pair from a reaction partner to form a chemical bond; denoted as E) replaces a hydrogen atom on the benzene ring, known as an addition-elimination reaction. This reaction occurs more readily when the benzene ring bears an electron-donating group (denoted as X), and the electrophilic substituent is either *ortho*- or *para*-directing on the ring since the reaction produces intermediate carbocations that are stabilized in these two positions.

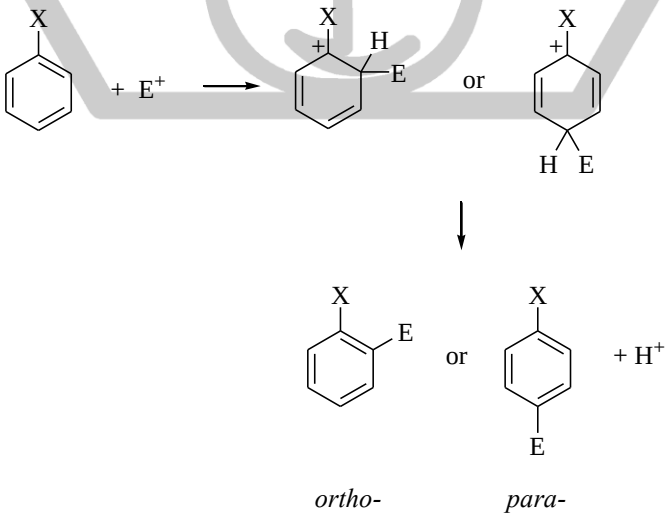
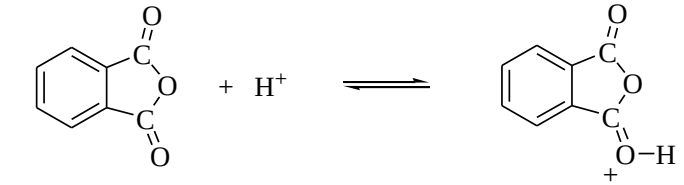


Figure 15-1 General mechanism for an electrophilic aromatic substitution reaction

In the synthesis of phenolphthalein, the aromatic reactant is phenol, which bears an electron-donating group, *i.e.* a hydroxyl group (–OH). The electrophilic reagent is the protonated phthalic anhydride (protonated by H_2SO_4) as shown in equation 15-1.



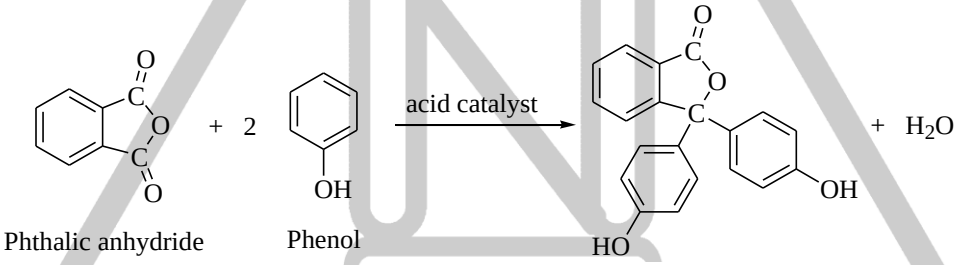
Phthalic anhydride

Protonated phthalic anhydride

(Electrophile)

(15-1)

The synthesis of phenolphthalein from phthalic anhydride is shown in equation 15-2.



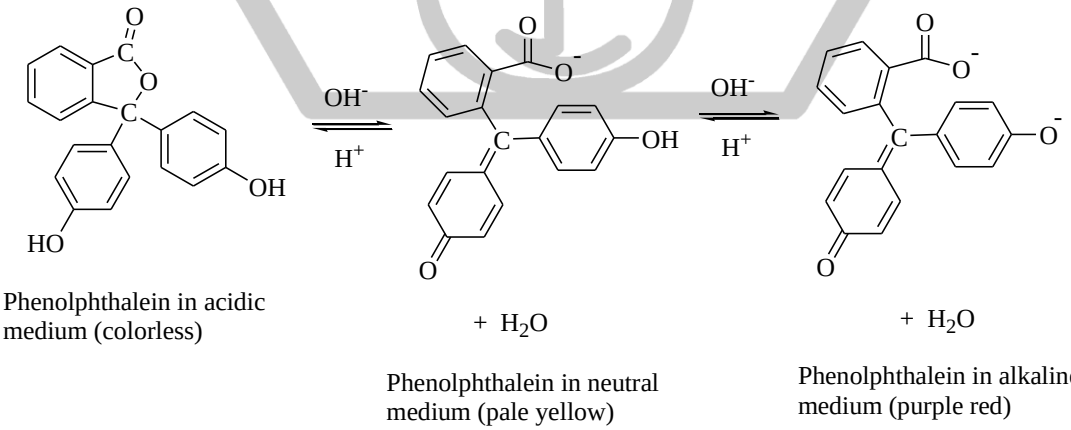
Phthalic anhydride

Phenol

Phenolphthalein

(15-2)

Since sulfuric acid is present in the reaction process, the product is in the acidic form. If sodium hydroxide is added to neutralize it, the weakly acidic hydroxyl group of the phenolic portion will dissociate and a quinoid structure will form. Further addition of the base to make the solution alkaline will cause deprotonation to produce a dianion that is purple-red. The reaction is reversible; if acid is added, equilibrium shifts to the left to form colorless phenolphthalein (Fig. 15-2).



Phenolphthalein in acidic medium (colorless)

Phenolphthalein in neutral medium (pale yellow)

Phenolphthalein in alkaline medium (purple red)

Figure 15-2 Structures and colors of phenolphthalein

II. Effect of substituent on color

If we replace phenol with guaiacol (*i.e. o*-methoxyphenol) to react with phthalic anhydride, we get guaiacolphthalein (15-3). Under alkaline conditions, this compound is blue, since its absorption wavelength shifts to the longer wavelength range (redshift) due to the presence of two additional substituents. This example demonstrates how the color of organic compounds can be influenced by a change in substituents, and thus the interesting phenomenon of color change (Fig. 15-3).

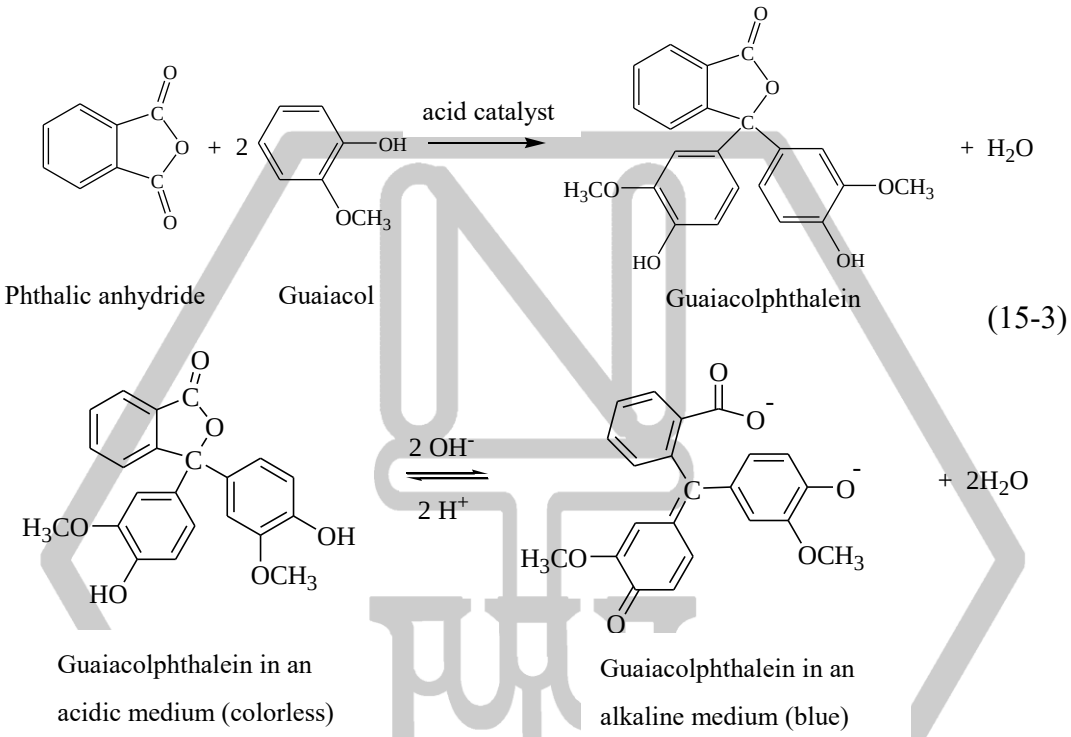
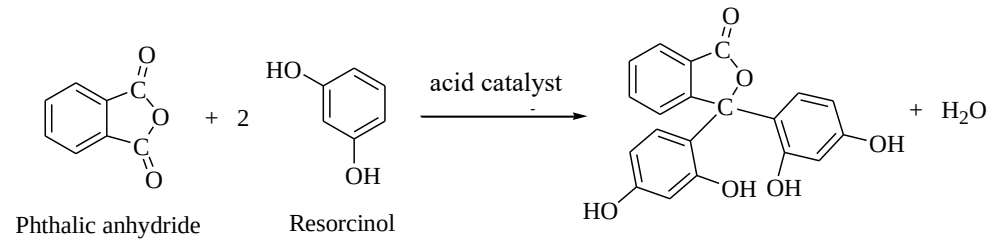


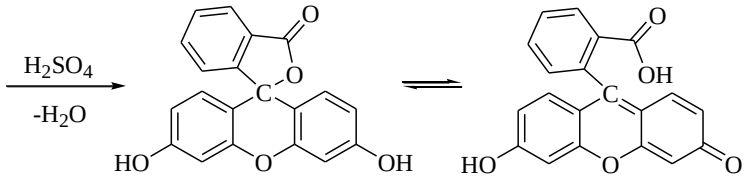
Figure 15-3 Structures and colors of guaiacolphthalein

III. Synthesis of fluorescein

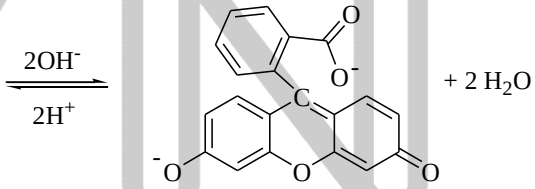
On the other hand, if we replace phenol with resorcinol (*i.e. m*-dihydroxybenzene) to react with phthalic anhydride, the product will have two adjacent hydroxyl groups that can be dehydrated and thus produce fluorescein (resorcinolphthalein). This fluorescein exists as tautomers in the solution state. When alkali is added, the acidic hydroxyl groups on the phenolic portion are deprotonated to give a dianion that can emit green fluorescence (Fig. 15-4).

In this experiment, a small amount of phthalic anhydride is mixed with phenol, guaiacol, or resorcinol in a test tube. Concentrated sulfuric acid is used as a catalyst. The product can be obtained after heating. Since the solubilities of the three products in water are low, after adding water, the products can be precipitated and separated from the solution, and then their properties are examined (Scheme 15-1).





Tautomer forms of fluorescein

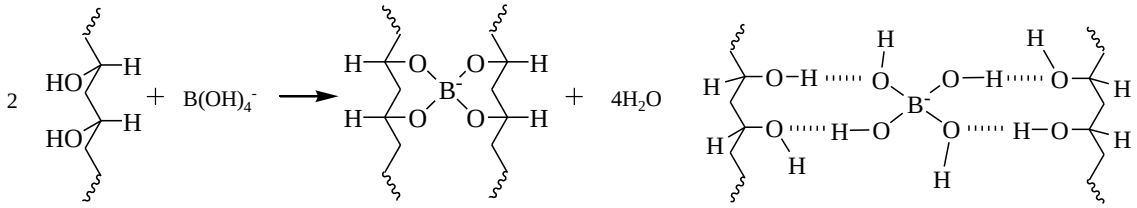


Green fluorescent substance in a basic solution

Figure 15-4 Structures and colors of fluorescein substances

IV. Synthesis of green fluorescent elastomer

The main component in the glue is the long-chain polymer polyvinyl alcohol (PVA). While adding some fluorescein in the glue, we obtain the fluorescent ink. If sodium tetraborate is added, the polymer chains can be connected through hydrogen bonds or covalent bonds to form a translucent elastic gel. This type of reaction is called cross-linking, that is, new bonds are formed between long chains of linear polymers (such as PVA) through the action of cross-linking agents (such as sodium tetraborate), making the polymer chains interconnected to form a network structure as shown in Fig. 15-5. Polyvinyl alcohol can also form hydrogen bonds with water. When the water content is higher, the gel will become more viscous, but the structure will be less strong. In this part, we add some synthetic fluorescent substances and sodium hydroxide solution into the PVA/borax solution and stir to obtain a green fluorescent elastomer.



(A) Cross-linking with covalent bonding (B) Cross-linking with hydrogen-bonding

Figure 15-5 The cross-linking between PVA polymer chains

Apparatus

Test tube (10), test tube rack, graduated cylinder (10 mL), glass rod, beaker (100 mL, 3), cotton bud, dropper, NBR gloves, cotton gloves, and activated carbon mask (self-prepared).

Shared: stirrer/hot plate, sand bath, digital thermometer, vortex mixer, UV lamp, and obscura.

Chemicals

Phthalic anhydride, $C_6H_4(CO)_2O$

Phenol, C_6H_5OH

Guaiacol (*o*-methoxyphenol), $CH_3OC_6H_4OH$

Resorcinol (*m*-dihydroxybenzene), $C_6H_4(OH)_2$

Concentrated sulfuric acid, 18 *M* H_2SO_4

1 *M* Sodium hydroxide, NaOH

1 *M* Hydrochloric acid, HCl(aq)

95% and 10% Ethanol, C_2H_5OH

Polyvinyl alcohol solution (PVA glue)

Sodium tetraborate decahydrate, $Na_2B_4O_7 \cdot 10\,H_2O$: 4 g/100 mL H_2O

Procedure

★ The chemicals used in this experiment are volatile and corrosive. Wear NBR gloves and avoid chemicals contacting the eyes and skin.

★ Perform heating in the fume hood, and use a test tube rack or beaker to place the test tubes.

★ Be sure to wash your hands after the experiment.

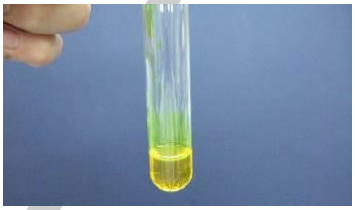
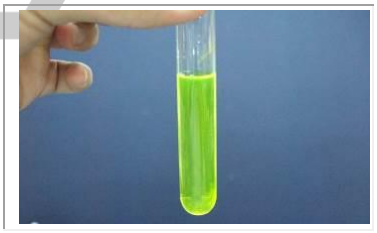
	Procedure	Illustration
I. Preparation of phenolphthalein indicator and test of its color change		
1.	Brush clean and oven-dry 5 test tubes in advance. Take 1/2 small spatula of phthalic anhydride and put it into a dry test tube. In a fume hood, add 2 drops of phenol and 1 drop of concentrated sulfuric acid to the test tube. Caution: Phenol and sulfuric acid are corrosive and should be handled with care.	

2.	Insert the test tube into the bottom of the sand bath with a temperature of about 150~200°C. Remove it from the sand bath every 10 s, gently shake the test tube to examine the reaction, and then put it back into the sand bath and repeat heating. Stop heating when the reaction mixture shows homogeneous orange-red color. Caution: The temperature of the sand bath is high. A cotton glove must be worn outside the NBR glove for heating operation to avoid burns. Note: Perform intermittent heating to avoid overheating that produces black by-products.	 
3.	Add 3 mL DI water to the reaction mixture. Take the test tube out of the fume hood and operate the following steps on your benchtop.	
4.	Use a glass rod to stir and mix the solution thoroughly. The product is insoluble in water and will precipitate out.	
5.	Allow the solid product to settle for a few minutes and decant the solution into the beaker for collecting the waste. Add 1 mL of 95% ethanol to the remaining solid in the test tube to dissolve it.	
6.	(1) Add 1 *M* NaOH to the solution drop by drop, and stir it until the solution is basic. Observe and record the color change. (2) Transfer half of this phenolphthalein basic solution to a clean test tube. Then add 1 *M* HCl to the solution drop by drop until it is acidic. Observe and record the color change. Keep the solutions in test tubes.	

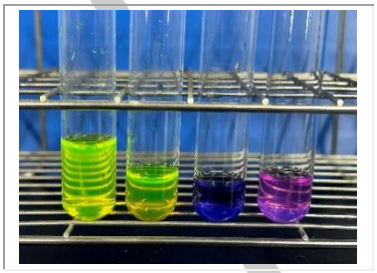
II. Effect of substituents on color

7.	Repeat synthetic procedures as in part I but replace phenol with 2 drops of guaiacol. Compare color changes of products upon addition of NaOH(aq) and HCl(aq). Note: This reaction is faster than the first one. Keep away from overheating.	

III. Synthesis of fluorescein

8.	Take 1/2 small spatula of phthalic anhydride and 1/2 small spatula of solid resorcinol; put them in a test tube. Add 1 drop of concentrated sulfuric acid.	
9.	Repeat steps 2~4 to synthesize fluorescein. Stop heating when the reaction mixture turns dark brown. Note: The fluorescein may decompose at its melting point (315°C). Move the the test tube in and out of the sand bath repeatedly to prevent overheating.	
10.	Add 1 mL of 95% alcohol to dissolve the product. Transfer several drops of the solution to another test tube. If the yield of product is high, use a glass rod to take out a portion of it and place it in another test tube for dissolution.	
11.	Dilute the fluorescein solution with 10% ethanol until the color is very light yellow. Add 1 *M* NaOH drop by drop to the diluted solution and observe the color change.	
12.	Place the test tube in a beaker, and put it under a UV lamp. Turn on the UV light with a long wave (366 nm), then switch to a short wave (254 nm), to examine the fluorescence alternatingly. Caution: Keep your eyes or skin away from UV exposure to avoid damage.	

IV. Preparation of highlighter pen and green fluorescent elastomer

13.	Take several drops of the fluorescein 95% ethanol solution obtained from step 10 in a beaker, and add several drops of 1 *M* NaOH and a proper amount of PVA glue. When the solution is uniformly mixed, wet a cotton bud with the sticky solution and try to write with this highlighter.	
14.	Add more PVA glue to the beaker. Stir with a glass rod to mix them well. Add sodium tetraborate solution drop by drop. Stir the mixture, and observe the color, viscosity, and elasticity changes of the PVA polymer.	 
15.	Keep and present the experimental results to the lab instructor when finishing the experiment.	
16.	(1) After finishing the experiment, rinse the test tubes and glass rod with 10% alcohol, and dispose of the solution into the waste container. (2) Brush clean the glassware with cleanser and tap water.	

Add ½ small spatula of phthalic anhydride	(1) Phenol, 2 d. (2) Guaiacol, 2 d. (3) Resorcinol, ½ small spatula	Add 1 d. conc. H_2SO_4	Heat to react ⇓ Observe changes in color and viscosity	Add water ⇓ Products precipitate out ⇓ Decant the supernatant	Dissolve solid products with 95% alcohol

Scheme 15-1 Summary of the synthesis of phenolphthalein and its derivatives